



NASA Nanotechnology Area Roadmap

Advanced Materials Partnership Forum

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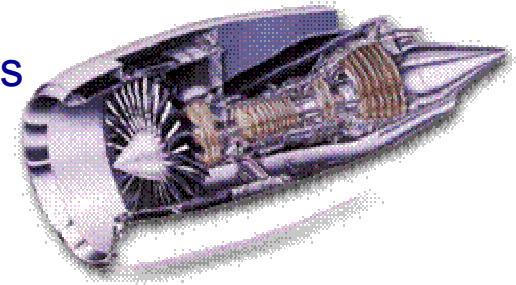
- **Benefits of Nanotechnology to NASA Missions**
- **Nanotechnology Space Technology Roadmap**
- **Office of Chief Technologist**

Critical Concerns for Aerospace Systems



Weight

- Reduced fuel consumption & emissions
- Reduced launch costs
- Enabler for many vehicles



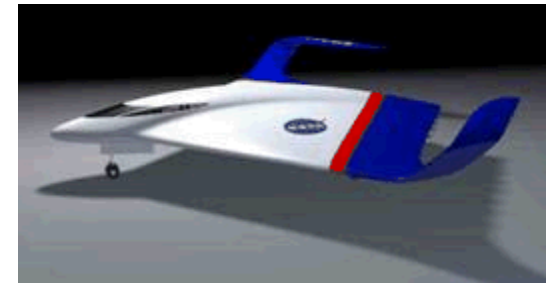
Functionality/Performance

- Reduced fuel or power consumption
- Multifunctionality – reduced weight



Durability

- Safety and reliability
- Maintenance down-time and costs



How Nanotechnology Impacts Materials Properties



Nanotechnology enables discrete control of desired materials properties :

➤ **Mechanical**

- Dictated by particle size (Griffith criteria), morphology and strength of interfaces (chemistry and roughness)
- High aspect ratios and surface areas radically change nanocomposite properties relative to host material
- Molecularly perfect, highly ordered, defect free structures, e.g. carbon nanotubes, lead to maximized properties (not just mechanical)

➤ **Thermal**

- Emissivity influenced by particle size and enhanced surface area/roughness
- Thermal conductivity controlled by particle size (phonon coupling and quantum effects) and nanoscale voids

➤ **Electrical**

- Nanostructure and defects influence conductivity and bandgap energy (conductivity, current density, thermoelectric effects)
- High aspect ratios enhance field emission and percolation threshold
- Nanoscale dimensions lead to inherent radiation resistance

➤ **Optical**

- Transparency and color dominated by size effects
- Photonic bandgap controlled by size ($\lambda/10$) and nanostructure



➤ **Reduced vehicle mass**

- Replace state-of-the-art with nanomaterials possessing superior mechanical properties
- Replace copper wiring with lightweight carbon nanotube wiring
- Eliminate parasitic weight by building in multifunctionality

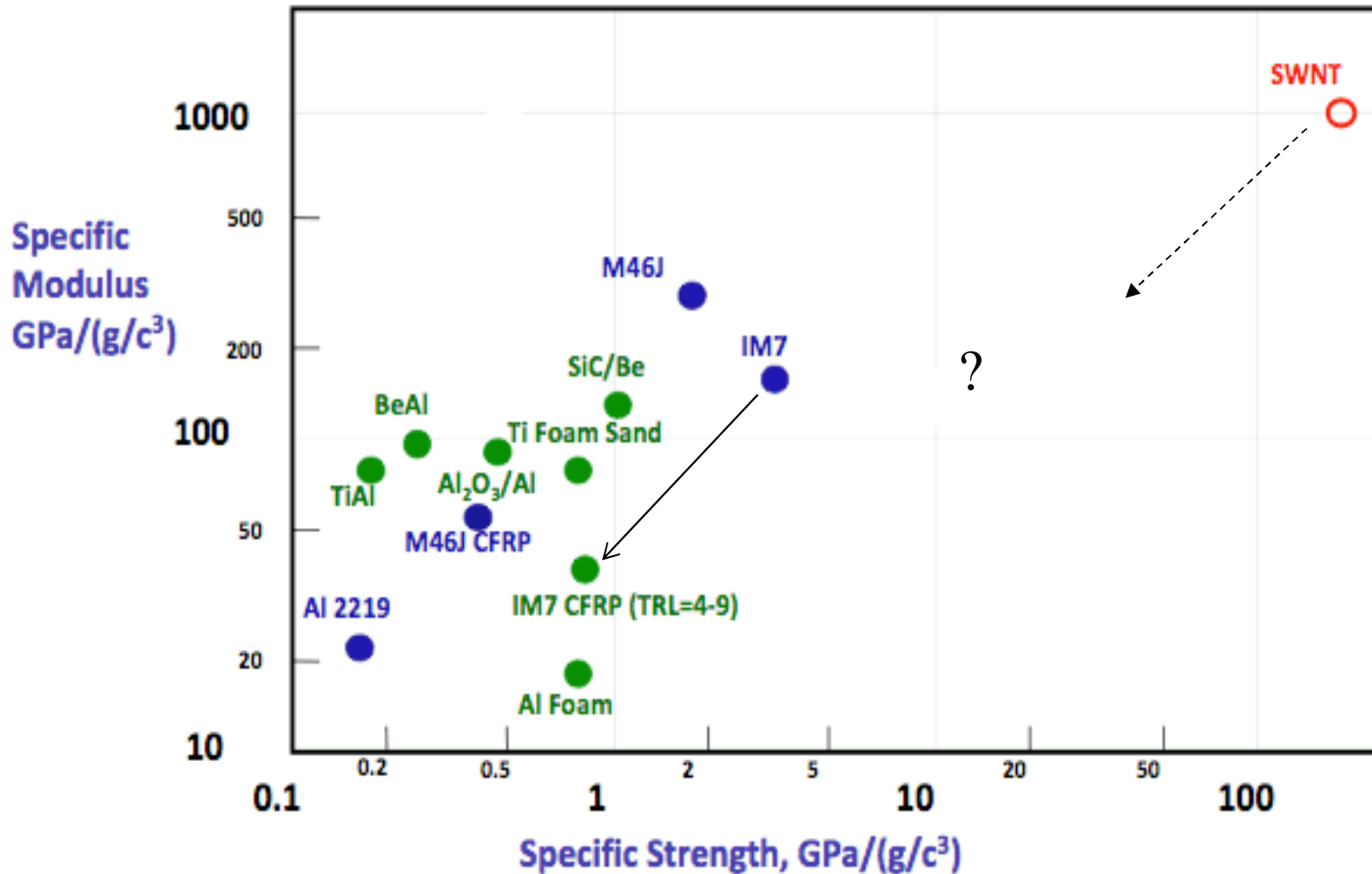
➤ **Enhanced durability**

- Oxidation resistant nanocomposite to improve high temperature resistance
- Toughening through addition of nanoscale fillers, “fuzzy fibers”, or nanotube tapes to improve low temperature ductility and damage tolerance
- Radiation resistant and fault tolerant electronics
- Engineer surface properties by nanotexturing (dust, icing, antimicrobial)

➤ **Improved performance**

- Increased surface area and reactivity (fuel cells, batteries, water and air purification, propellants)
- Better selectivity (sensors, detectors)
- >50% efficiency flexible photovoltaics
- Lightweight, high efficiency, embedded energy harvesting

Why NASA?

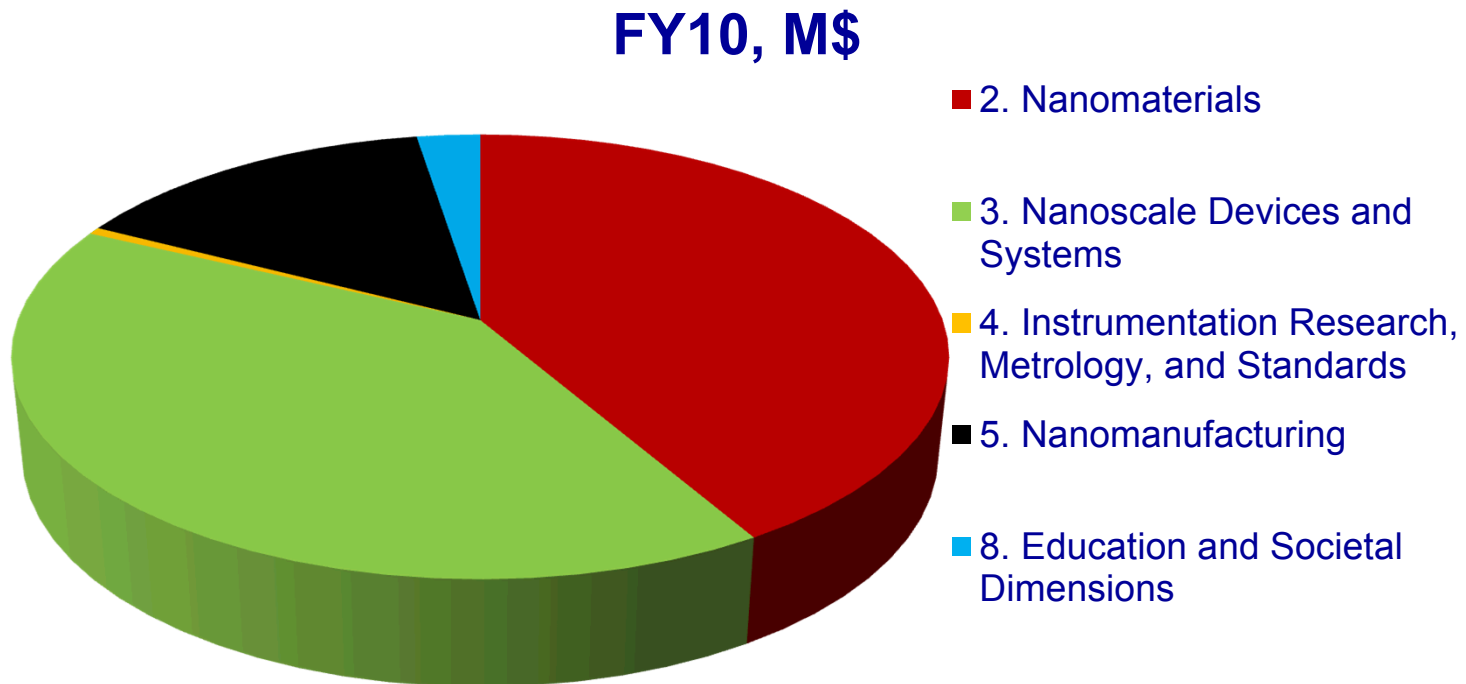


Property improvements could enable reduction in vehicle weight of 30%

Background



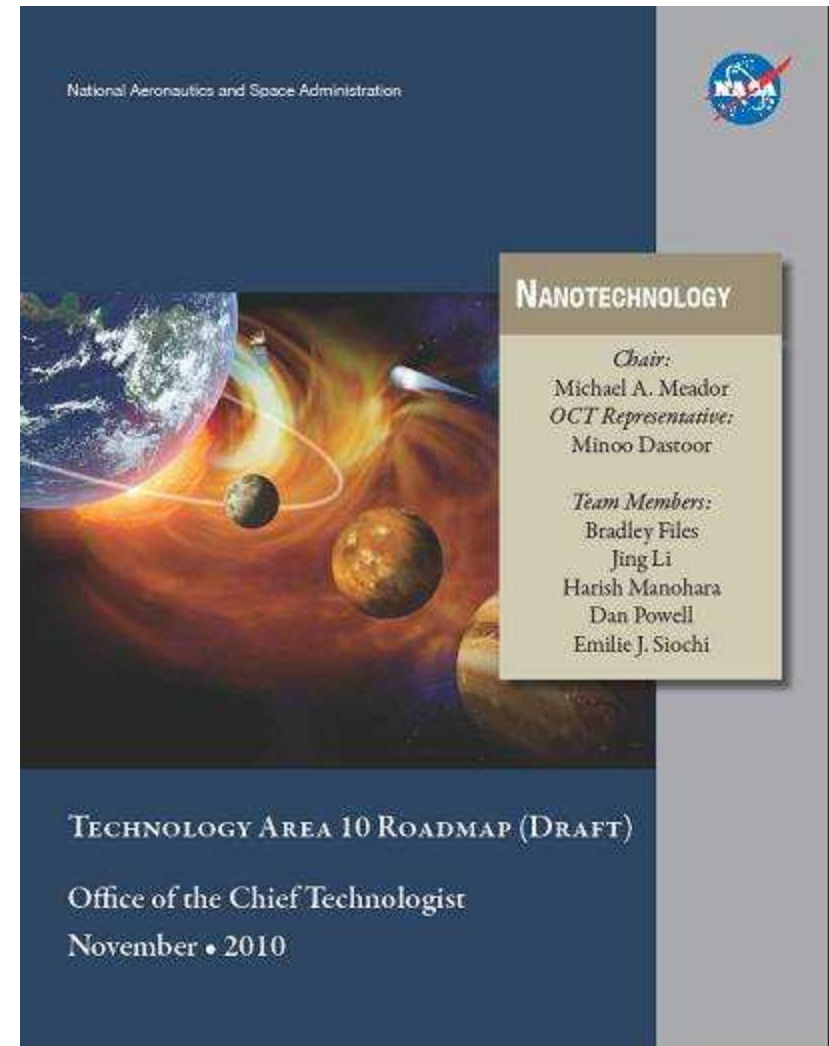
- **The National Nanotechnology Initiative was founded in 2001**
 - NASA was one of the founding agencies
 - NASA nanotechnology funding peaked around 2004 at ~\$60M, current investment is \$19M – includes \$9M in SBIR/STTR
 - Office of Chief Technologist strongly interested in revitalizing program



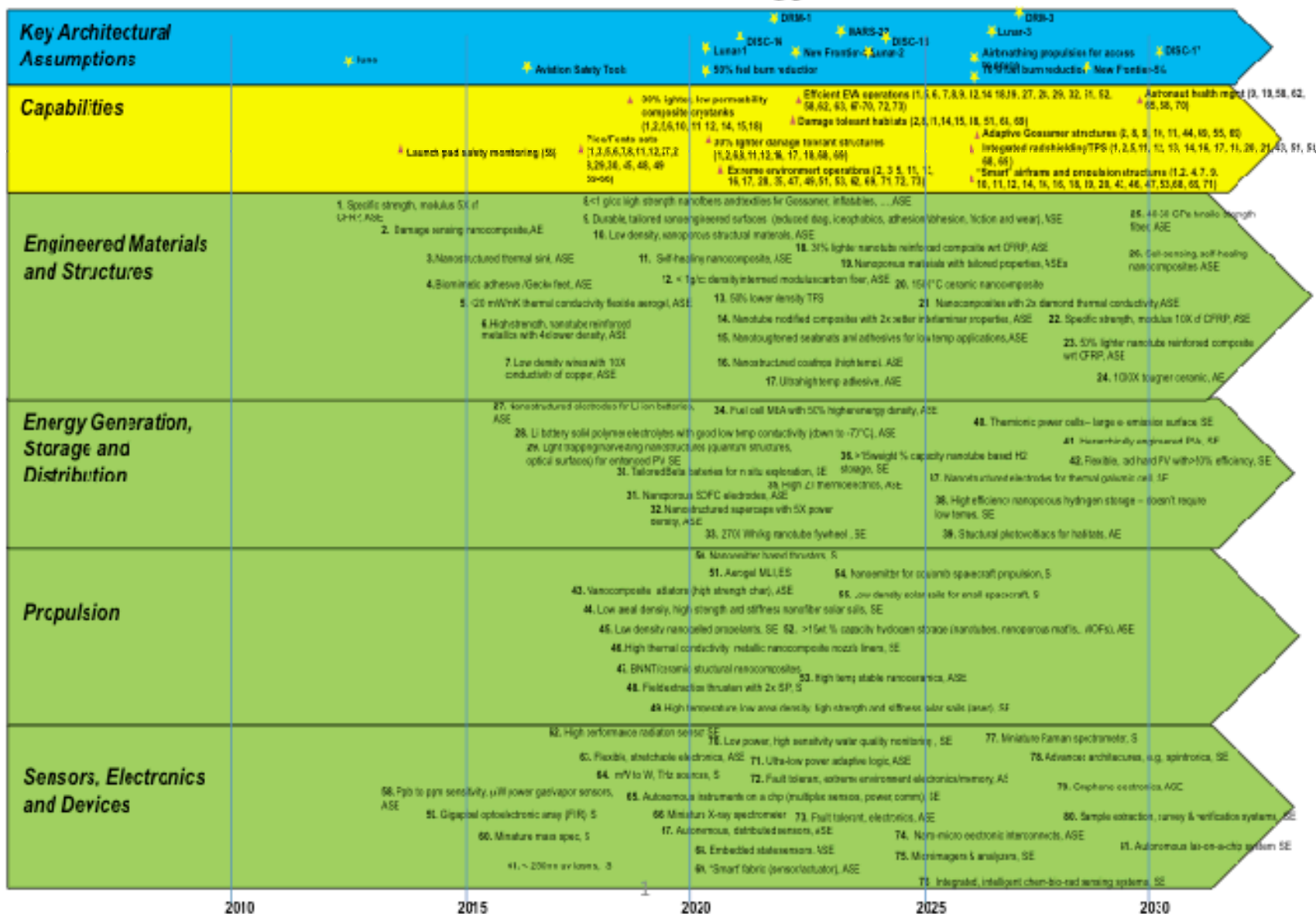
NASA Nanotechnology Roadmap



- **Drafted 20+ year technology roadmap for development of nanotechnology (TRL 6) and its insertion into NASA missions**
 - One of 14 roadmaps sponsored by Office of Chief Technologist – increased NASA investment
 - Includes both mission “pull” and technology “push”
 - Covers four theme areas
 - Engineered Materials and Structures
 - Energy Generation, Storage and Distribution
 - Propulsion
 - Sensors, Electronics and Devices
 - Used to guide future funding decisions
- **Roadmaps vetted by NRC**
 - Public comment via website and workshops
 - Panel of experts reviewed each roadmap
 - Identified technology gaps
 - Comment on content and timing
 - Recommendations on funding priorities – within each roadmap and across all
 - Final report delivered to NASA in Dec.



Nanotechnology Roadmap



Key Capability

30% Lighter Cryogenic Propellant Tanks

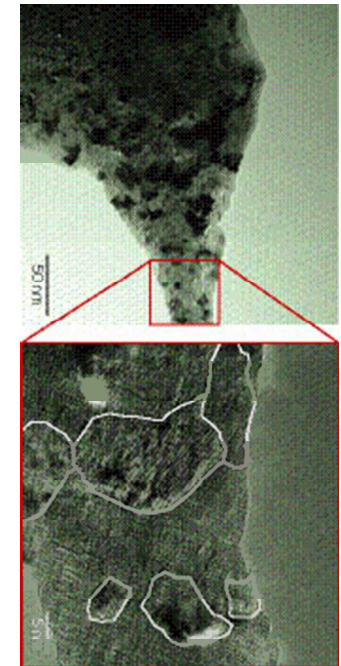
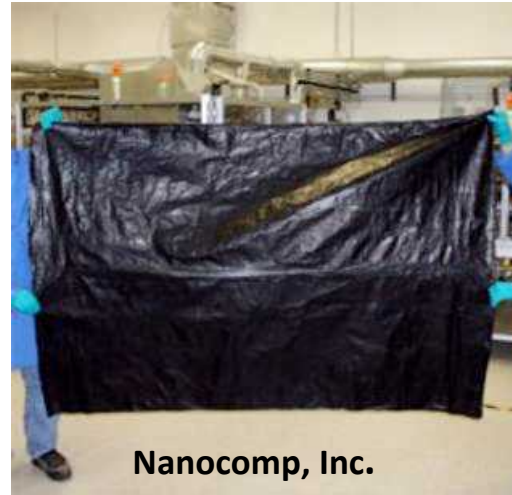


Objective: Reduce dry mass of aerospace vehicles by reducing cryogenic propellant tank mass by 30%

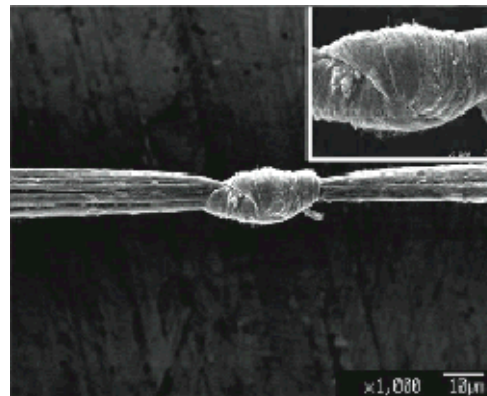
- Cryotanks account for up to 50% of vehicle dry mass

Approach: Replace conventional Al-Li alloys, composites and multilayer insulation with:

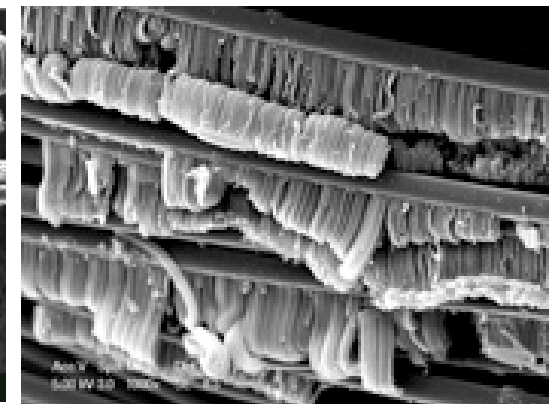
- Low permeability, damage tolerant nanocomposites
- High strength and stiffness nanotube-based fibers
- Multifunctional, durable insulation
- Ultrahard nanocrystalline metals



LLNL



Windle, Cambridge



Wardle, MIT

Key Capability

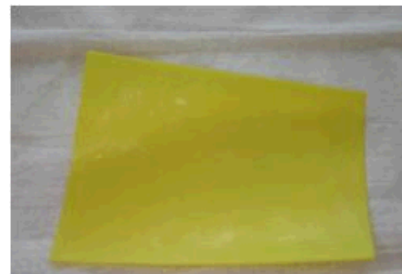
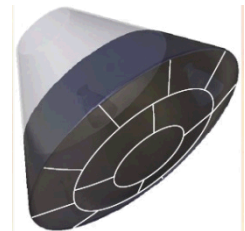
Thermal Protection and Management



Objective: Reduce mass and improve efficiency of thermal control systems

Approach: Replace conventional carbon-phenolic ablators, multilayer insulation, Al radiators and straps and heat pipes with:

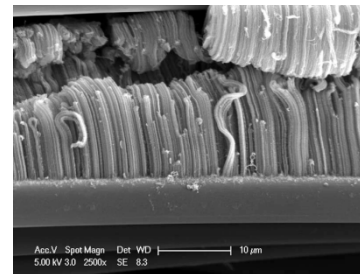
- Nanocomposite based TPS
- Flexible, high temperature, mechanically robust nanoporous materials
- Nanocomposites with 2X thermal conductivity of diamond
- “Fuzzy” fiber reinforced composites for radiators and heat exchangers



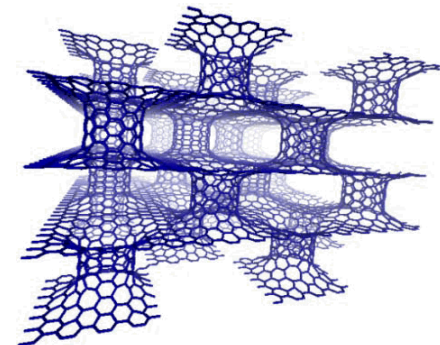
**Polyimide Aerogels
(NASA)**



**CNT/Poly(azomethine)
Ablators (NASA)**



**CNT Decorated Carbon
Fibers (MIT)**



**Pillared Graphene
(AFOSR)**

Key Capability

“Smart” Airframe and Propulsion Components



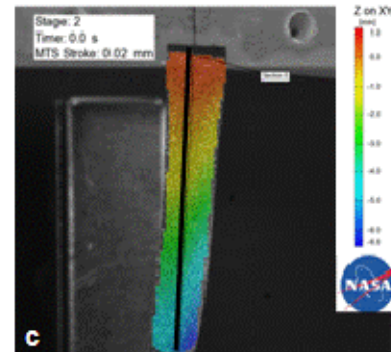
Objective: Develop durable structural components capable of sensing their condition and/or environment and adapting to it

Approach: Replace materials with embedded sensors, mechanical actuators, enable on-site repair with:

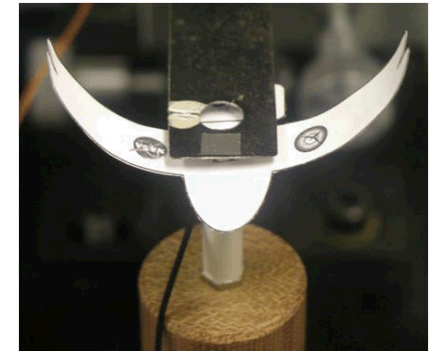
- Self-sensing and adaptive nanocomposites
- Self-healing materials
- Multifunctional nanocomposites



CNT Sheets, Fabric and Wire (Nanocomp, General Nano, FSU)



Optical strain/displacement measurement on magnetic nanocomposites (NASA)



CNT Actuator (NASA)

Key Capability

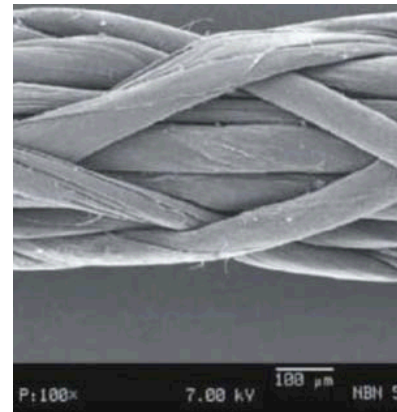
Adaptive Gossamer Structures



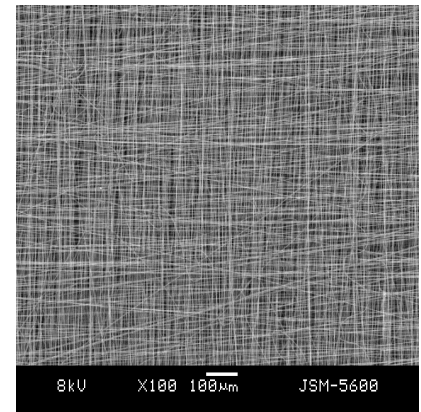
Objective: Develop ultralightweight, durable, “smart” fibers and fabrics for use in solar sails, habitats, antenna and solar cell arrays

Approach: Replace thin, high strength polymer (polyimide) films with:

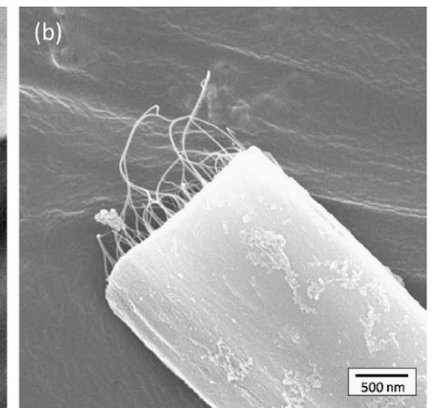
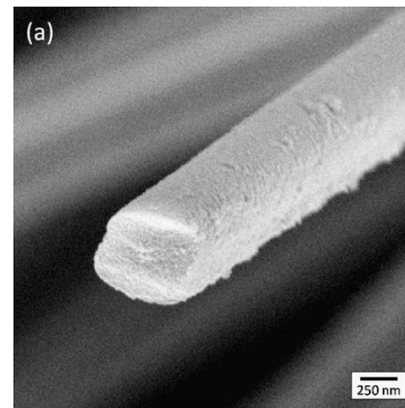
- Ultralightweight films and fibers
- Controlled CTE nanocomposite membranes
- Adaptive materials with tunable emissivity and reflectivity
- High strength conductive fibers for tethers



Braided CNT Fibers
(*Nanocomp*)



Electrospun Membrane (NASA)



PAN/CNT Derived Carbon Fiber (*Ga Tech*)

Grand Challenge: Ultralightweight Structural Nanomaterials



Objective: Reduce density of state-of-the-art structural composites by 50% and equivalent or better properties.

Approach: Use nanomaterials with combination of high performance characteristics

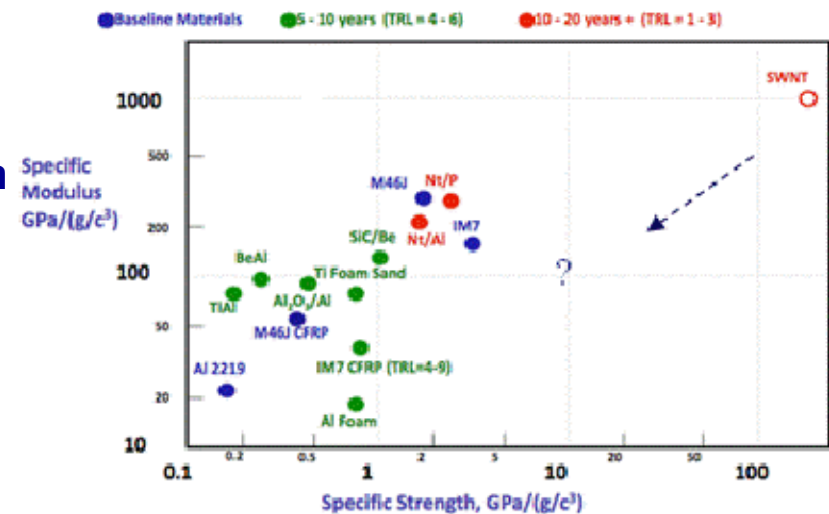
- Utilize nanostructured additives to produce low density carbon nanotube fibers with properties equivalent to aerospace grade intermediate modulus fibers but at half the density
- Develop nanomaterials based structural components that take advantage of mechanical properties observed at the nanoscale
- Enhance damage tolerance by enhancing interlaminar properties of nanocomposites

State-of-the-Art:

- Aluminum and titanium alloys, carbon fiber reinforced polymeric composites, ceramic matrix composites, metal matrix composites

NASA Benefits/Applications:

- Potential vehicle dry mass savings of up to 30%
- Enhanced damage tolerance for improved safety
- Enable design concepts with tailored performance
- Enabling technology for environmentally friendly vehicles
- Enabling technology for extreme environment operations



Technical Challenges to TRL 6:

- Development of reliable, reproducible, and controlled nanomaterials synthesis process on a large scale
- Development of tailored geometries at nano and macro scale for structural components
- Fabrication methods that can be practically implemented at bulk or macro scale
- Early assessment of systems payoffs in cost, operational safety and reliability.

Time to Mature to TRL 6: 5-10 years

Potential for Partnering with Other Agencies:

- Partnerships under NNI Nanomanufacturing SI

Grand Challenge: Graphene Electronics

Objective: Develop high-speed, high-density, rad-hard, flexible next generation electronics as an alternative to SOA CMOS technology.

Approach: Employ graphene, a single layer (or 2 – 9 layers) sheet of carbon atoms with a single (0001) basal plane graphite structure.

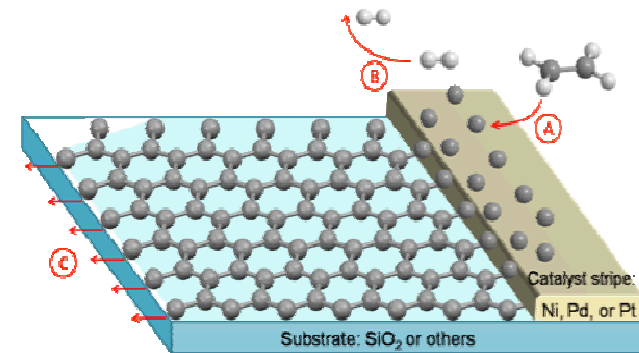
- Has the highest electron mobility $\sim 200,000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ of any material yet tested.
- High flexibility (breaking strength $\sim 100 \text{ GPa}$), and low optical absorbance ($\sim 2\%$) in the visible region rendering it a transparent conductor.

State-of-the-Art:

- CMOS technology using Si, Si-Ge (for low temperature and rad-hard), SiC and GaN (high temperature and rad-hard).

NASA Benefits/Applications:

- Lightweight electronics with little or no shielding
- Enabling technology for prolonged missions to extreme environments
- Enabling technology for smart, programmable materials for crew habitat and EVA suits



One of large area Graphene synthesis processes using metal catalysts; Adsorbed hydrocarbons are reduced to form condensed Graphene sheet

Technical Challenges to TRL 6:

- Development of reliable, reproducible, and controlled graphene synthesis process on a large scale
- Clear understanding of graphene and dielectric interfaces
- Foundry-conducive processes to produce large scale electronic circuits
- Addressing heterogeneous system integration issues

Time to Mature to TRL 6: 15 years

Potential for Partnering with Other Agencies:

- Partnerships under NNI Nanoelectronics Signature Initiative

Grand Challenge: Nanopropellants



Objective: Develop alternatives to conventional cryogenic propellants and hypergolics with simpler handling and storage requirements and lower toxicity

Approach: Utilize metal and inorganic nanoparticles in fuel mixtures.

- High surface areas lead to increased rates of oxidation and good burning rates
- High surface areas can increase interactions with conventional propellants leading to gelation

State-of-the-Art:

- Nanoscale aluminum/ice nanopropellant launched small rocket 1300 ft. (Purdue, PSU)
- Metal and aerogel nanoparticle gelation of liquid hydrogen and hydrocarbon fuels successfully demonstrated

NASA Benefits/Applications:

- Simplified launch pad operations and in-space propellant storage and transfer
- Possibility of producing particles by ISRU
- Applications in Exploration, Aeronautics (Hypersonics)



Technical Challenges to TRL 6:

- Development of passivation chemistries to reduce surface oxidation and improve safety that do not adversely affect combustion
- Scalable synthesis methods to produce large quantities with good batch-to-batch consistency and that can enable tailoring of size and morphology to control burn characteristics

Time to Mature to TRL 6: 5 years

Potential for Partnering with Other Agencies:

- Current Purdue/Penn State research effort supported jointly by NASA and AFOSR
- Collaboration with DoD on scale-up

Grand Challenge: Structures with Integrated Energy Generation and Energy Storage



Objective: Develop structural materials with integrated capabilities such as batteries, supercapacitors, and photovoltaics.

Approach:

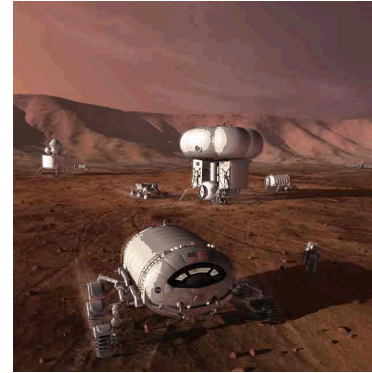
- Design new systems where the storage capacity is inherent in the structural material, or where energy generation can be made the outer layer of the structure. The same material may also serve as MMOD protection and energy distribution.

State-of-the-Art:

- Separate systems for structure, energy generation, and energy storage
- Batteries at 90 Wh/kg at C/10 & 30° C

NASA Benefits/Applications:

- Integrated systems with lighter overall mass
- Structures inherently provide energy systems without needing to design separate systems



Rovers, habitats, or EVA suits could have embedded energy systems

Technical Challenges to TRL 6:

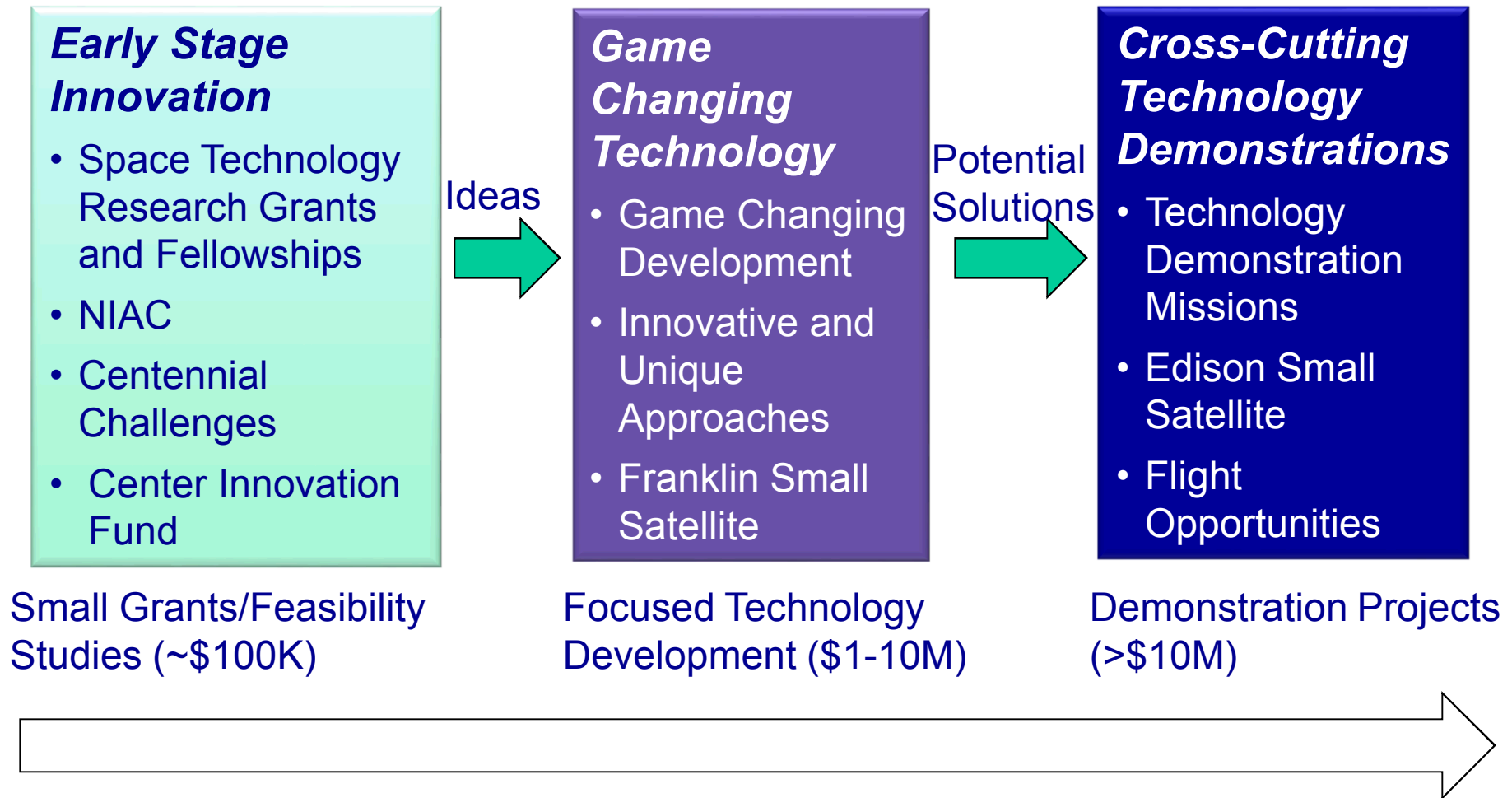
- Development of reliable, reproducible, and controlled nanomaterial synthesis process on a large scale
- Joint project work needed between energy systems and structures
- Packaging issues to take laboratory results to the system level for testing
- Considerable system engineering and integration issues

Time to Mature to TRL 6: 20 years

Potential for Partnering with Other Agencies:

- DOE, DOD

Office of Chief Technologist Program



Technology Readiness Level



- **NASA has a renewed interest in nanotechnology R&D**
 - OCT Nanotechnology Roadmap
 - Nanotechnology Project
- **There are opportunities for participation for universities and industry in NASA nanotechnology R&D**
 - OCT Nanotechnology Project
 - Space Technology Grants and Fellowships
 - Others

Opportunities for Funding and Students



- **Grant funding opportunities announced by NRAs**
- **SBIR, STTR**
- **NASA Space Technology Research Fellowships (NSTRF)**
- **NASA Graduate Student Research Program**
- **NASA Postdoctoral Program**
- **Summer Faculty Fellowship**
- **Undergraduate Student Research Program**
- **Summer Internships - LARSS**
- **Co Ops**